1. Handling Anomalous Residuals in Implemented Solutions to Precipitation Truncation Problem in WSR-88D PPS Algorithm

1.1 Background

A longstanding problem of underestimation of precipitation estimates in the WSR-88D Precipitation Processing System (PPS) algorithm, due to the cumulative effect of slight truncations in the algorithm calculation, was described in last year's MOU Report among the NEXRAD Program, the WSR-88D Operational Support Facililty[1] and the NWS Office of Hydrology[2] (Seo et al., 2000). In Section 3 of that report, it was explained and documented that precipitation deficits due to the truncation problem were directly related to the steadiness (rather than the intensity) of an event; were consequently of greatest significance (in terms of percentage of quantitative precipitation underestimation) in light, stratiform precipitation events and of least significance in heavy, convective downpours; and that the effect was worse in the hourly-based accumulation products such as OHP, THP, USP and DPA (up to 2.0 mm (.08") per hour) than in the cumulative Storm Total product, STP (up to 0.5 mm (.02") per hour).

1.2 Proposed Solutions to Truncation Problem

Two algorithmic solutions to this problem were formulated. One, dubbed the "Simple Fix", simply corrects all known instances of truncation but retains the inherent resolution of the algorithm's integer formulation at .1 mm. The other, dubbed the "Complete Fix", changes the inherent resolution of the algorithm to .01 mm and thus affords greater accuracy in the calculation and also allows the accumulation of very light precipitation amounts due to low reflectivity echoes (e.g., 22 - 26 dBZ with the default Z-R coefficients) not measurable in the present algorithm. Both of these were coded on the in-house, Office of Hydrologic Development (OHD) PPS development system; the first was targeted for implementation in Open RPG (ORPG) Build 1, while the second was deferred until ORPG Build 2, due to its increased complexity and the enhanced risk associated with its implementation. Preliminary tests performed on these solutions on the OHD PPS development system showed both to perform satisfactorily and as intended, with no anomalies noticed.

1.3 Residuals Problem

1.3.1 Problem Revealed

Upon implementation and more extensive testing of the "Simple Fix" on the target, ORPG operational system, a problem was uncovered in the hourly-based accumulation products[3], however, whereby trace precipitation amounts were evident in some areas that did not experience reflectivity echoes above the signal-to-noise threshold during the corresponding accumulation period, but had experienced rainfall earlier. These trace amounts apparently represent anomalous residuals from the earlier event. The phenomenon is revealed in Figures 1 and 2, below, from a replay-simulation performed on the ORPG utilizing Archive II data from the Houston radar

(KHGX) for the time period (08/21/98 21 UTC - 08/22/98 04 UTC). This simulation captures the effects of a tropical storm as its rainbands traversed the radar coverage area from east to west. Fig. 1 (a-h) shows successive Hybrid Scan Reflectivity (HSR) images from approximately the top of each clock-hour throughout the simulation period. Fig. 2 (a-d) shows successive One Hour Precipitation (OHP) images at the corresponding times for the last four clock-hours of the replay (i.e., 08/22/98 01 UTC - 04 UTC). (Note that Figs. 2 (a-d) correspond to Figs 1 (e-f).)

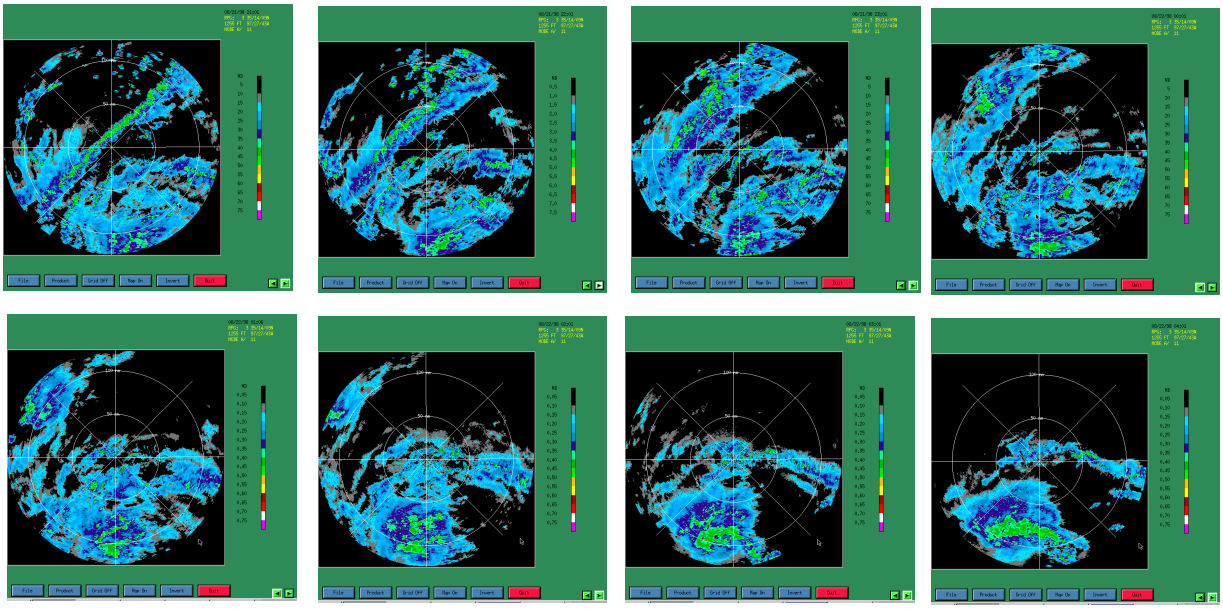

Fig. 1 (a-h): Hybrid Scan Reflectivity (HSR) products from Houston, TX (KHGX) at top of hours from 08/21/98 ~21 UTC through 08/22/98 ~04 UTC (across top, then bottom rows). Captured using XPDT tool on ORPG.

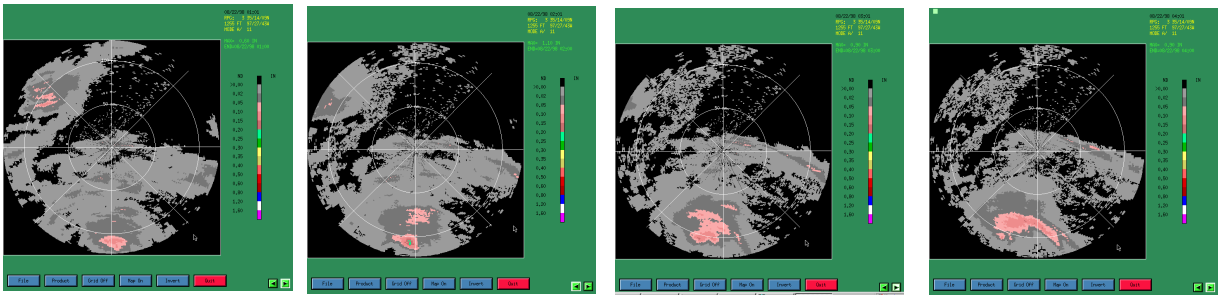

Fig. 2 (a-d): One Hour Precipitation (OHP) products from Houston, TX (KHGX) at top of hours from 08/22/98 ~01 UTC through 08/22/98 ~04 UTC. From simulation performed with "Simple Fix" version of PPS algorithm.

The "residuals" phenomenon is particularly evident in the northwest quadrant of the latter OHP products. It is seen there that, as the last visible radar echoes retreat from the area to the west and none remain that could cause rainfall, "speckles" of very light accumulation (in the range >0.0 - .02") remain from echoes that overswept the area hours earlier. Particularly note that these speckles do not change from one hour to the next. Other evidence of residuals is seen

in a region to the southeast that is also echo free during the last few hours of the simulation.

1.3.2 Problem Explained

Investigation into the PPS Algorithm formulation revealed the problem to be a consequence of the methodology of the computation of hourly-based accumulations and the (0.1mm) resolution of the algorithm. All hourly-based accumulations in the PPS algorithm (after the first hour) are determined via a methodology whereby a "running hourly rainfall total" field is maintained by adding in new contributions from the most recent scan-to-scan period at each gridpoint, and subtracting out old contributions from any periods (or fractions of periods) phased out of the hour. During the entire cycle of precipitation at a given gridpoint (i.e., from beginning to end of an event), this methodology sometimes results in the fractions of accumulation added in not exactly equaling the fractions subtracted out, thus resulting in a slightly non-zero accumulation at the end of the event. Negative "residuals" of this type are reset to zero, but positive residuals cannot be discerned from "real" accumulation and are, thus, maintained in the running-hourly-total field. Thereafter, hourly accumulations at such gridpoints will sustain these residual amounts - even though no longer raining at those locations - until a rain-free hour occurs over the entire radar coverage area and the running-hourly-total field is reset to zero.

1.3.3 Solutions Considered for ORPG Build 1

Although these residuals are of small magnitude (fractions of mm), their presence was deemed qualitatively unacceptable. One option considered was a reversion to the present, operational version of the PPS algorithm, which manifests the original Precipitation Truncation problem. OHP products from the last four hours of a simulation performed with that version under the same parameters as above are shown in Fig. 3 (a-d).

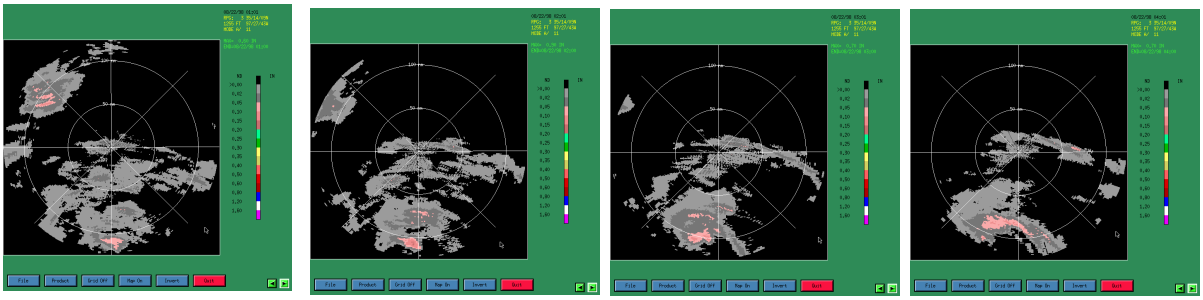

Fig. 3 (a-d): One Hour Precipitation (OHP) products from Houston, TX (KHGX), as per Fig. 2 (a-d), but from simulation performed with pre-ORPG Build 1 operational version of PPS algorithm (i.e., containing "Truncation Problem").

It is seen that the Residuals phenomenon is not present with this algorithm version. However, comparison to Figures 2 (a-d) reveals that, in the areas where the reflectivity field supports precipitation (e.g., to the south of the radar), accumulations are diminished - in some

places, considerably so. For the reasons detailed in last year's MOU report, precipitation deficits of this magnitude were deemed unacceptable, and this option rejected.

The solution decided upon was to retain the "Simple fix" version of the PPS algorithm in ORPG Build 1 but to implement a filter upon the running-total hourly accumulation field that resets very light accumulations to zero just before creation of all the hourly-based accumulation products. (Note that a non-filtered version of the running-hourly-total field is always retained for use the next volume scan). Selection of the filter level, of course, can be tricky, since "real" accumulations will be discarded along with the residuals. One source of guidance is the in-house OHD PPS system, which utilizes default color scales on the graphical products that lump trace amounts (up to .25 mm (.01")) together with zero accumulations, effectively acting like a filter (unlike the ORPG default display scales, which distinguish any non-zero accumulations from exactly zero amounts). Indeed, this filtering effect is the likely reason why the "Residuals Problem" was not revealed until the "Simple Fix" to the original, Precipitation Truncation problem was run on the target, ORPG system.

Another consideration, though, is that this Residuals effect becomes more pronounced the longer precipitation is sustained (before the running-total precipitation fields are reset to zero due to a rain-free hour across the radar coverage area). Indeed, some residuals were observed above the .25 mm inherent filter level on the in-house PPS system in some long-sustained events. Ultimately, it was decided to set the filter level in the algorithm at 0.5 mm (.02"); with all values below that level discarded and values at or above it retained. Results of another simulation performed under the same circumstances as above but with this software version (i.e., "Simple Fix with Filter") are shown in Figures 4 (a-d).

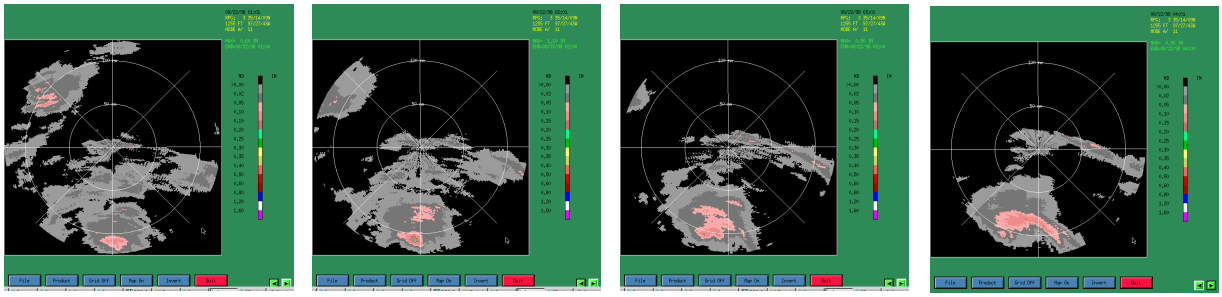

Fig. 4 (a-d): One Hour Precipitation (OHP) products from Houston, TX (KHGX), as per Fig. 2 (a-d), but from simulation performed with PPS algorithm version containing fix to "Truncation Problem" with Filter at .5 mm (.02") leve1.

Upon superficial examination, Figs. 4 (a-d) appear to resemble Figs. 3 (a-d), in terms of total area covered by precipitation, because neither manifest residual accumulations. But upon closer scrutiny, the quantitative precipitation deficits in Figs.3, due to the uncorrected Precipitation Truncation problem, become plainly evident, as seen in the higher accumulation groupings (e.g., dark gray (>.02"); pink (>0.5")).

Comparison of Figs. 4 (a-d) to Figs. 2 (a-d) reveal them to be very similar, quantitatively, particularly in the higher accumulation groupings, while the anomalous residuals have been removed in Figs. 4. Thus, the application of the filter appears to have achieved the desired result. (Other runs (not shown), have yielded similar, satisfactory results.) Therefore, it was recommended that the version of the PPS software containing the "Simple Fix" to the Precipitation Truncation problem with a Filter (at the .5 mm level) applied upon the hourly-based accumulation display fields, be implemented in ORPG Build 1. It is not anticipated, though, that some Residuals may never be seen in any of the hourly-based accumulation products, particularly during long-sustained precipitation events, for the reasons cited above.

1.3.4 Solutions Considered for ORPG Build 2

Though not scheduled for operational implementation until ORPG Build 2, the version of the PPS algorithm containing the "Complete Fix" to the Precipitation Truncation problem (see above) was next coded on the ORPG and run under the same conditions as the other simulations, above. Results are seen in Figs. 5 (a-d).

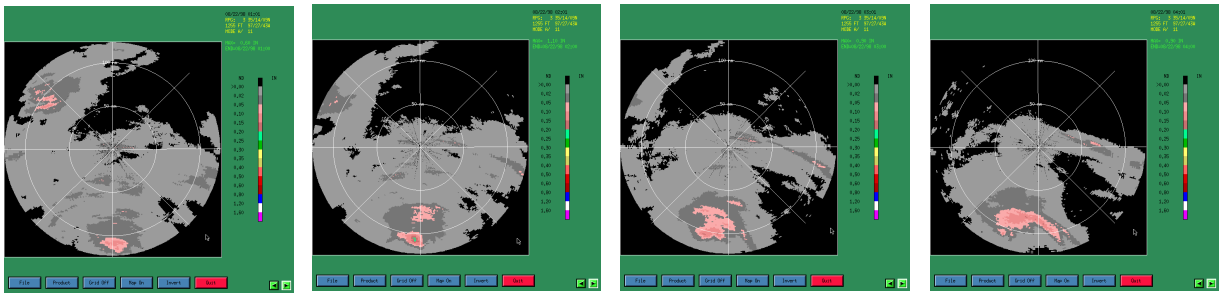

Fig. 5 (a-d): One Hour Precipitation (OHP) products from Houston, TX (KHGX), as per Fig. 2 (a-d), but from simulation performed with PPS algorithm version containing "Complete Fix" to "Truncation Problem" (without filter).

Comparison of this version to the others reveals it to more accurately portray the actual precipitation totals than any other version. Regions with or without measurable precipitation, in each instance, are consistent with the Hybrid Scan Reflectivity fields during the corresponding hours (see Figs. 1 (a-h)). In regions with substantial precipitation (e.g., to the south and southwest) it yields essentially the same results as the Simple Fix with Filter version, while in other regions, it reveals very light accumulations due to low dBZ echoes not measurable or filtered with the other methods. And few or no Residuals are seen.

However, because the version with the "Complete Fix" also utilizes a "running hourly total" methodology and integer arithmetic (though at an enhanced resolution), the eventual emergence of Residuals with this method was still deemed possible, although to a far lesser degree than in the "Simple Fix" version. Indeed, precipitation was sustained for many hours beyond 08/22/98 04 UTC in the Houston tropical storm event that was replayed above, and when the simulation with the "Complete Fix" was continued (for another 12 hours), some residuals did, indeed, emerge. Figs. 6 (a-d) display HSR products from this extended run, from 13 to 16

UTC. on 08/22/98 (i.e., through ~17 hours of simulated time). Figs. 7 (a-d) display OHP products from the corresponding times.

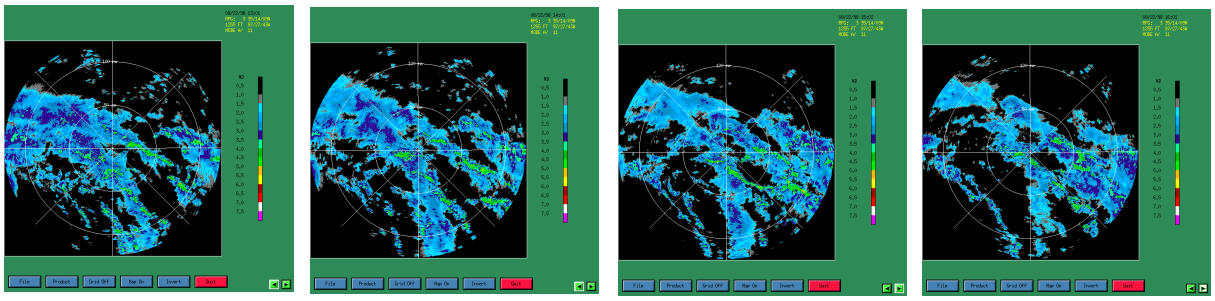

Fig. 6 (a-d): Hybrid Scan Reflectivity (HSR) products from Houston, TX (KHGX) at top of hours from 08/22/98 ~13 UTC - 16 UTC. From simulation begun at 08/21/98 ~21 UTC.

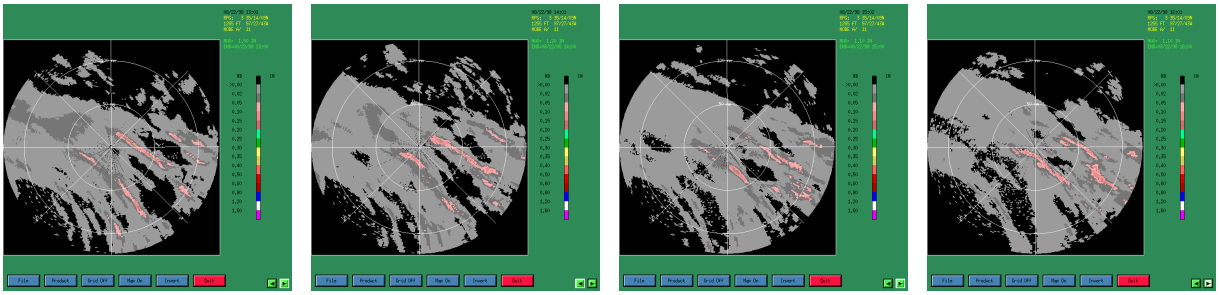

Fig.7 (a-d): One Hour Precipitation (OHP) products from Houston, TX (KHGX) at top of hours from 08/22/98 ~13 UTC - 16 UTC. From simulation begun at 08/21/98 ~21 UTC. with “Complete Fix” to “Truncation Problem” (without filter)

Upon close examination, scattered speckles of light accumulation not changing from one hour to the next are observed in the OHP products (e.g., at far range, beyond the reflectivity echoes to the southwest), indicative of Residuals. To address this situation, a filter was implemented in this version as well, though at a very low level, (i.e. at or above 0.2 mm (.008")). When the extended simulation was rerun with this filter, results were as seen in Figs. 8 (a-d).

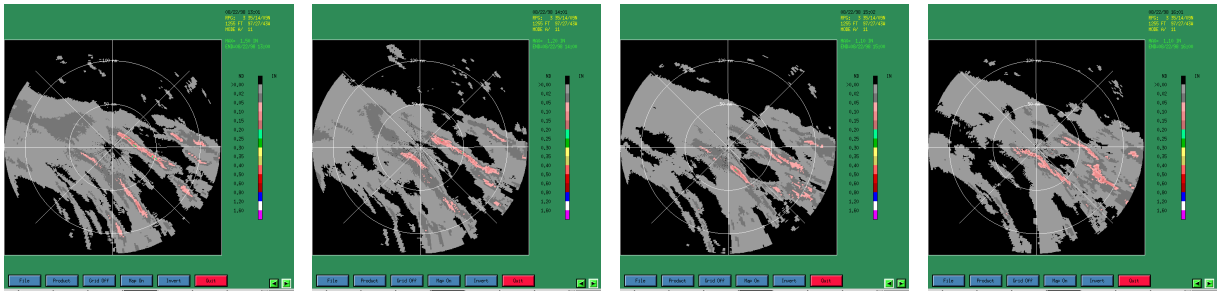

Fig.8 (a-d): One Hour Precipitation (OHP) products from Houston, TX (KHGX), as per Fig. 7 (a-d), but from simulation performed with PPS version containing "Complete Fix" to "Truncation Problem", with Filter at .2 mm (.008") level.

Comparison to Figs. 7 (a-d) reveals the Residuals to have vanished, although at the lightest color-display level, some precipitation free areas are seen to have appeared as a consequence of the filter. At the higher accumulation levels, however, the two sets of images are identical. Thus, the "Complete Fix" solution with a very low-level filter is deemed to be quite satisfactory.

1.4 Conclusions and Future Considerations

It is recommended and anticipated that the "Simple Fix with Filter" (at .5 mm (.02")) solution to the Precipitation Truncation problem will be implemented in ORPG Build 1, and the "Complete Fix with Filter" (at .2 mm (.008")) solution implemented in ORPG Build 2.

It should be noted that, ultimately, an algorithmic solution may be sought that would correct the Precipitation Truncation problem without introducing Residuals and hence, the need for a Filter that, unavoidably, eliminates some very small but real accumulations. However, any such solutions presently under consideration (e.g., convert all disk files from 2-byte integer to 4-byte real; abandon "running hourly total" methodology in favor of reconstructing hourly accumulations "from scratch" each volume scan) would significantly increase computer resource utilization, including CPU, disk space needed (by over one megabyte) and disk I/O.

[1] Since renamed Radar Operations Center.

[2] Since renamed Office of Hydrologic Development.

[3] The Storm Total Precipitation (STP) product, which is not hourly based, is unaffected.

References

Seo, D.-J. and coauthors, 2000: Final Report, Interagency Memorandum of Understanding among the NEXRAD Program, WSR-88D Operational Support Facility, and the NWS Office of Hydrology. [Available at http://www.nws.noaa.gov/oh/hrl/papers/2000mou_pdf/Mou00_PDF.html]